The Commonwealth of Massachusetts
Executive Office of Health and Human Services
Department of Public Health
250 Washington Street, Boston, MA 02108-4619

November 3, 2005

Mat Moran, Health Agent
Westminster Board of Health
Town Hall - P.O. Box 456
Westminster, MA 01473

Dear Mr. Moran:

Enclosed is a copy of the report concerning the IAQ assessment of the Westminster Town Hall. The report shows that there were problems identified. Please refer to the recommendations section for advice on how to correct these problems.

If you have any questions regarding the report or if we can be of further assistance in this matter, please feel free to call us at (617) 624-5757.

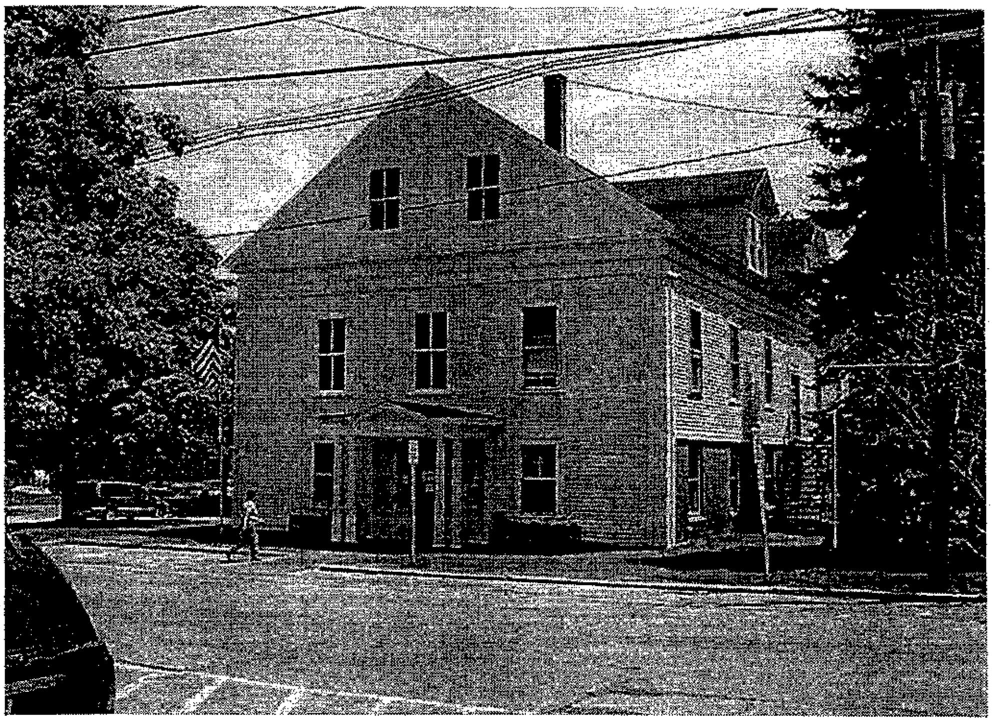
Sincerely,

Michael A. Feeney, R.Ph., J.D., C.H.O., Director
Emergency Response/Indoor Air Quality, CEH

Enclosure
cc: Suzanne K. Condon, Associate Commissioner, Center for Environmental Health
Thomas P. O'Toole, Chairman, Board of Selectmen
Senator Robert A. Antonioni
Representative Lewis G. Evangelidis

INDOOR AIR QUALITY ASSESSMENT

Westminster Town Hall
3 Bacon Street
Westminster, Massachusetts



Prepared by:
Massachusetts Department of Public Health
Center for Environmental Health
Emergency Response/Indoor Air Quality Program
November 2005

Background/Introduction

At the request of Mat Moran, Health Agent for the Westminster Board of Health, the Massachusetts Department of Public Health's (MDPH) Center for Environmental Health (CEH) provided assistance and consultation regarding indoor air quality at the Westminster Town Hall (the town hall), 3 Bacon Street, Westminster, Massachusetts. Concerns about odors/water penetration in the building commissioner's office prompted the request. On June 3, 2005, a visit was made to this building by Michael Feeney, Director of Emergency Response/Indoor Air Quality (ER/IAQ), CEH, to conduct an indoor air quality assessment.

The town hall is a three-story, clapboard-sided, wood frame structure, constructed in 1837. The first floor contains town offices. The second floor contains an auditorium and offices. The uppermost floor is unoccupied. A furnace room is attached to the rear of the building. Windows appear to be original wooden sash windows and are openable throughout the building. The building is built upon a small crawlspace.

The town hall had undergone major structural refitting to preserve the structural soundness of the building. Substantial stabilization and repairs to portions of the roof and uppermost level were done in 2000. The topmost level contains a series of iron tie rods (Pictures 1 and 1A) that connect the floor/auditorium ceiling to the ridge beam of the roof. This design would transfer the weight of the floor/auditorium ceiling and materials on the floor (called load), which would pull downward on the roof peak. This load would then be transferred to the roof rafters, which would then push outward on the exterior wall of the building. In order to provide roof support, horizontal beams connected to the rafters were inserted into a vertical wooden beam (called and mortise and tenon joint)

(Figure 1) (Picture 2). The mortise and tenon joints were held in place by a metal strap wrapped around the vertical beam and nailed into the horizontal beam with metal spikes (Picture 3). In this fashion, the outward thrusting of the roof rafters would be arrested by these horizontal/vertical beams.

At some point previous to the assessment, a combination of heavy snow on the roof, combined with the weight of materials stored on the uppermost floor exceeded the capacity for the wooden vertical beams to carry load. This conclusion is supported by the following conditions noted in and outside the town hall.

- A number of vertical beams were either cracked at or around the iron strapping (Picture 4). Once a beam cracks, its ability to bear load is significantly reduced.
- One vertical beam had split entirely. It appears that a type of composite compound was applied to re-establish the integrity of the beam (Picture 5).
- Supplemental steel supports (Picture 6) appear to be connected to the roof edge to the vertical support beams.
- A gap, (estimated to be 2 inches) exists between the auditorium ceiling and gypsum wallboard (GW) used to subdivide the auditorium (Picture 7). Since GW has minimal elastic quality and is extremely susceptible to compression, this gap appears to have been created when the repairs to the beams raised the ceiling *upwards*.
- The north second floor wall appears to bulge outwards when examined from the northwest corner of the building (Picture 8). This bulging roughly corresponds to the worst beam damage noted on the uppermost level.

These repairs appear to have stabilized the structure. Whether the uppermost floor can be used for any activity that requires it to carry a significant load (beyond roof snow) is not certain. This damage to the building does not appear to be directly related to the odors reported on the first floor, but may affect remediation recommendations made in this report (installation of gutter and downspouts to drain rainwater from the roof).

Methods

Air tests for carbon dioxide, temperature and relative humidity were taken with the TSI, Q-Trak, IAQ Monitor Model 8551. CEH staff also performed a visual inspection of building materials for water damage and/or microbial growth.

Results

The town hall has an employee population of 20 and can be visited by approximately 50 to 100 people daily. Tests were taken during normal operations and results appear in Table 1.

Discussion

Ventilation

It can be seen from the tables that carbon dioxide levels were above 800 parts per million (ppm) of air in three of fourteen areas surveyed. Please note that some rooms were unoccupied during the assessment, which can greatly reduce carbon dioxide levels. Carbon dioxide levels in the building would be expected to be higher during periods of higher occupancy.

Fresh air ventilation is delivered by unit ventilators (univents) that were retrofitted into the building. A univent draws fresh air from a vent on the exterior of the building and air from the room (called return air) through a vent in the base of its case (Figure 2). Fresh air and return air are mixed, filtered, heated and provided to rooms through an air diffuser located in the top of the unit. The univents were deactivated during the assessment. The town hall originally had a large room on the first floor serviced by a single univent. The auditorium was also originally a large open room, provided with heat by two univents. Both floors were subdivided into offices without apparent consideration of the location of ventilation systems. Offices were created by construction of interior walls using paneling or GW. In one instance an interior wall was constructed over the univent casing on the first floor (Picture 9). Routine filter changing and maintenance cannot be done on this univent without dismantling the interior wall. Hence, the first floor has two rooms with one univent that was covered by an interior wall. All other rooms on the first floor have no mechanical ventilation. The second floor had some of the auditorium divided into offices which have no mechanical ventilation. The auditorium has two univents that were deactivated during this assessment.

Exhaust ventilation in the first floor is provided by a ducted hallway vent which is likely connected to a fan above the furnace room (Picture 10). This vent was sealed with plywood (Picture 11) and the fan appeared to be deactivated. Without functional mechanical supply or exhaust ventilation, environmental pollutants can accumulate within the building and lead to poor air quality/comfort complaints. To maximize air exchange, the MDPH recommends that windows be used to provide airflow during business hours.

During summer months, ventilation is controlled by the use of openable windows. The building was configured in a manner to use cross-ventilation to provide comfort for building occupants. The building is equipped with windows on opposing exterior walls. Open hallway doors maintain a pathway for airflow. This design allows for airflow to enter an open window, pass through a room and an open door, enter the hallway, pass through the opposing open room door, into that room and exit the building on the leeward side (opposite the windward side) (Figure 2). With all windows and hallway doors open, airflow can be maintained in a building regardless of the direction of the wind. This system fails if the windows or doors are closed (Figure 3). Most hallway doors in the building were open during the assessment.

To maximize air exchange, the MDPH recommends that both supply and exhaust ventilation operate continuously during periods of occupancy. In order to have proper ventilation with a mechanical supply and exhaust system, the systems must be balanced to provide an adequate amount of fresh air to the interior of a room while removing stale air from the room. It is recommended that HVAC systems be re-balanced every five years to ensure adequate air systems function (SMACNA, 1994). The date of the last balancing of these systems was not available at the time of the assessment. The mechanical ventilation system, in its current condition, cannot be balanced.

The Massachusetts Building Code requires a minimum ventilation rate of 20 cubic feet per minute (cfm) per occupant of fresh outside air or have openable windows in each room (SBBRS, 1997; BOCA, 1993). The ventilation must be on at all times that the room is occupied. Providing adequate fresh air ventilation with open windows and maintaining the temperature in the comfort range during the cold weather season is impractical. Mechanical ventilation is usually required to provide adequate fresh air ventilation.

Carbon dioxide is not a problem in and of itself. It is used as an indicator of the adequacy of the fresh air ventilation. As carbon dioxide levels rise, it indicates that the ventilating system is malfunctioning or the design occupancy of the room is being exceeded. When this happens a buildup of common indoor air pollutants can occur, leading to discomfort or health complaints. The Occupational Safety and Health Administration (OSHA) standard for carbon dioxide is 5,000 parts per million parts of air (ppm). Workers may be exposed to this level for 40 hours/week, based on a time-weighted average (OSHA, 1997).

The Department of Public Health uses a guideline of 800 ppm for publicly occupied buildings. A guideline of 600 ppm or less is preferred in schools due to the fact that the majority of occupants are young and considered to be a more sensitive population in the evaluation of environmental health status. Inadequate ventilation and/or elevated temperatures are major causes of complaints such as respiratory, eye, nose and throat irritation, lethargy and headaches. For more information on carbon dioxide see Appendix A.

Temperature readings measured within a range of 71° F to 74° F, which was within the MDPH recommended comfort range of 70° F to 78° F. In many cases concerning indoor air quality, fluctuations of temperature in occupied spaces are typically experienced, even in a building with an adequate fresh air supply. Temperature control is often difficult in a building with abandoned or nonfunctioning ventilation systems.

The relative humidity in the building ranged from 44 to 54 percent, which was also within the MDPH recommended comfort range. The MDPH recommends a comfort range of 40 to 60 percent for indoor air relative humidity. While these measurements are within the recommended comfort range, the relative humidity measurements when compared to outdoors indicate a possible source of water vapor that exists within the building. Of note is that indoor relative humidity measurements exceeded outdoor measurements by a range of 4 to 17 percent. Such a disparity between indoor and outdoor relative humidity occupancy indicates that a possible source of water vapor in the building may be exhaled breath of occupants in a building without a functioning exhaust ventilation system and/or water accumulation in the crawlspace. The highest relative humidity was measured in the building commissioner's offices, the location of the reported odor (see the Microbial/Moisture Concerns section of this assessment). Moisture removal is important since the sensation of heat conditions increases as relative humidity increases (the relationship between temperature and relative humidity is called the heat index). As indoor temperature rises, the addition of more relative humidity will make occupants feel hotter. If moisture is removed, the comfort of the individuals improves. Removal of moisture from the air, however, can have some negative effects. Relative humidity in the building would be expected to drop below comfort levels during the heating season. The sensation of dryness and irritation is common in a low relative humidity environment. Low relative humidity is a common problem during the heating season in the northeast part of the United States.

Microbial/Moisture Concerns

The absence of a gutter/downspout system (Pictures 12 and 13) may have a role in water accumulating in the building, particularly under the building commissioner's office. The exterior brick walls along the north side of the first floor are stained green with moss at approximately three feet above ground level, indicating chronic exposure to splashing rainwater from the non-guttered roof. Along the edge of the foundation of the town hall are a series of pits (Picture 14) as well as a tarmac apron. The purpose of these pits is to provide passive ventilation for the crawlspace to prevent odor and moisture accumulation. Each of these crawlspace vents was sealed with plywood and the seams caulked with foam insulation material (Picture 15). According to Board of Health personnel, the vents were sealed in this manner to prevent intrusion by pests (e.g., rodents). By blocking these vents, water vapor and other crawlspace pollutants will tend to vent *into* the building creating odors and moisten building components. In addition, buildings are normally constructed to allow for water to flow away from exterior walls, particularly if the building has a crawlspace or cellar. The purpose of the tarmac apron is to direct rainwater away from the exterior walls. The tarmac apron was buried under soil on the south wall and damaged along the north wall in a manner that allows for water to accumulate against the foundation (Pictures 16 and 17). In both instances, water is likely to accumulate against the exterior wall and penetrate the crawlspace.

Moist weather tends to travel in a northeasterly track up the Atlantic coast towards New England (Trewartha, G.T., 1943). Wet weather systems generally produce south/southwesterly winds, which will expose the south and west facing walls to driving rain more often than the east and north walls. Of note is the location of the building commissioner's office. A blocked crawlspace vent exists just outside the window for this office, which is directly exposed to driving rain from the south/southwest. The other crawlspace vent on this side of the building is generally sheltered by a large pine tree in the southwestern corner of the town hall's lot. Therefore, it appears likely that rainwater is accumulating beneath the building commissioner's office, which as it evaporates, may increase the relative humidity in this office (the relative humidity measured during the assessment was higher than that outdoors).

With a possible water source within the crawlspace evaporating into the building, the most likely material to support mold growth and associated odors is the wall-to-wall carpet in the building commissioner's office. The American Conference of Governmental Industrial Hygienists (ACGIH) and the US Environmental Protection Agency (US EPA) recommend that porous materials be dried with fans and heating within 24 to 48 hours of becoming wet (ACGIH, 1989; US EPA, 2001). If porous materials are not dried within this time frame, mold growth may occur. Water-damaged porous materials cannot be adequately cleaned to remove mold growth. The application of a mildewcide to porous materials is not recommended.

A musty odor was noted upon entering the town hall. A walk-off carpet exists at the main entrance, which is installed over wall-to-wall carpet (Picture 18). The rubber matting of the walk-off carpet tends to trap moisture and preventing the carpeting from drying. It is likely that the source of musty odors is the wall-to-wall carpet. Please note that the carpeting is installed over a tile floor. Old floor tile may contain asbestos and should be remediated in a manner consistent with Massachusetts asbestos laws.

Other IAQ Evaluations

Univents are normally equipped with filters that strain particulates from airflow. MDPH staff checked the univent filters and found that the univent filters installed in the town hall are of a type that provides minimal filtration of respirable dusts. In order to decrease aerosolized particulates, disposable filters with an increased dust spot efficiency can be installed. The dust spot efficiency is the ability of a filter to remove particulates of a certain diameter from air passing through the filter. Filters that have been determined by ASHRAE to meet its standard for a dust spot efficiency of a minimum of 40 percent would be sufficient to reduce airborne particulates (Thornburg, 2000; MEHRC, 1997; ASHRAE, 1992). Note that increased filtration can reduce airflow produced by univents due to increased resistance, or pressure drop. Prior to any increase of filtration, a ventilation engineer should evaluate each univent to ascertain whether it can maintain function with more efficient filters.

Conclusions/Recommendations

In view of the findings at the time of the visit, occupant complaints are consistent with what might be encountered in a building accumulating water in a crawlspace. The sealing of the crawlspace vents combined with the lack of ventilation can produce stale air, enhance moisture movement into the building, and result in odors. Based on the observations made at the town hall, the following recommendations are made:

1. Since univents are inoperable, the sole source of fresh air is through windows. In order to adjust temperature and provide fresh air, the opening

of windows, to the extent practicable, is recommended. To aid in the draw of fresh outdoor air in warm weather, use portable fans directing air out windows on the leeward side of the building. Fans positioned in this manner will serve to increase the draw of outdoor air across the floor without interfering with the natural internal airflow pattern of the building.

2. Remove plywood from crawlspace vents to enhance airflow. Install wire mesh over each opening to prevent pest infiltration.
3. Install a gutter and downspout system along the roof edge.
4. Until a gutter and downspout system can be installed, construct temporary, water proof shelters over each crawlspace vent to prevent water intrusion
5. Seal holes in the floors, walls and ceilings for pipes and cables to prevent infiltration of pollutants from wall cavities. Each univent cabinet should be examined for holes in floor and walls and be rendered airtight.
6. To prevent moisture penetration into the crawlspace, the following actions should be considered:
   a. Reestablish the integrity and grade of the tarmac apron to drain rainwater from the foundation.
   b. Remove foliage to no less than five feet from the foundation.
   c. Improve the grading of the ground away from the foundation at a rate of 6 inches per every 10 feet (Lstiburek, J. & Brennan, T.; 2001).

7. Examine each univent for function. Survey rooms for univent function to ascertain if an adequate air supply exists. Consider consulting a heating, ventilation and air conditioning (HVAC) engineer concerning the calibration of univent fresh air control dampers.
8. Remove all blockages from univents and exhaust vents.
9. Operate both supply and exhaust ventilation continuously during periods of occupancy.
10. Consider having ventilation systems re-balanced/calibrated every five years by an HVAC engineering firm.
11. For buildings in New England, periods of low relative humidity during the winter are often unavoidable. Therefore, scrupulous cleaning practices should be adopted to minimize common indoor air contaminants whose irritant effects can be enhanced when the relative humidity is low. To control for dusts, a high efficiency particulate arrestance (HEPA) filter equipped vacuum cleaner in conjunction with wet wiping of all surfaces is recommended. Avoid the use of feather dusters. Drinking water during the day can help ease some symptoms associated with a dry environment (throat and sinus irritations).
12. Install filters in window-mounted air conditioning units that conform to manufacturer's instructions. Clean the window-mounted air conditioners before and after activation in accordance with manufacturer's instructions.
13. Ascertain whether tile under carpet contains asbestos and remediate in a manner consistent with state and federal laws related to asbestos.

14. Refer to resource manuals and other related indoor air quality documents for further building-wide evaluations and advice on maintaining public buildings. These materials are located on the MDPH's website at http://www.state.ma.us/dph/beha/iaq/iaqhome.htm.

15. Consult "Mold Remediation in Schools and Commercial Buildings" published by the US EPA (2001) for further information on mold. Copies of this document can be downloaded from the US EPA website at: http://www.epa.gov/iaq/molds/mold_remediation.html.

References

ACGIH. 1989. Guidelines for the Assessment of Bioaerosols in the Indoor Environment. American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

ASHRAE. 1992. Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter. American Society of Heating, Refrigeration and Air Conditioning Engineers. ANSI/ASHRAE 52.1-1992.

BOCA. 1993. The BOCA National Mechanical Code-1993. 8th ed. Building Officials & Code Administrators International, Inc., Country Club Hills, IL. M-308.1

MEHRC. 1997. Indoor Air Quality for HVAC Operators & Contractors Workbook. MidAtlantic Environmental Hygiene Resource Center, Philadelphia, PA.

OSHA. 1997. Limits for Air Contaminants. Occupational Safety and Health Administration. Code of Federal Regulations. 29 C.F.R. 1910.1000 Table Z-1-A.

SBBRS. 1997. Mechanical Ventilation. State Board of Building Regulations and Standards. Code of Massachusetts Regulations. 780 CMR 1209.0

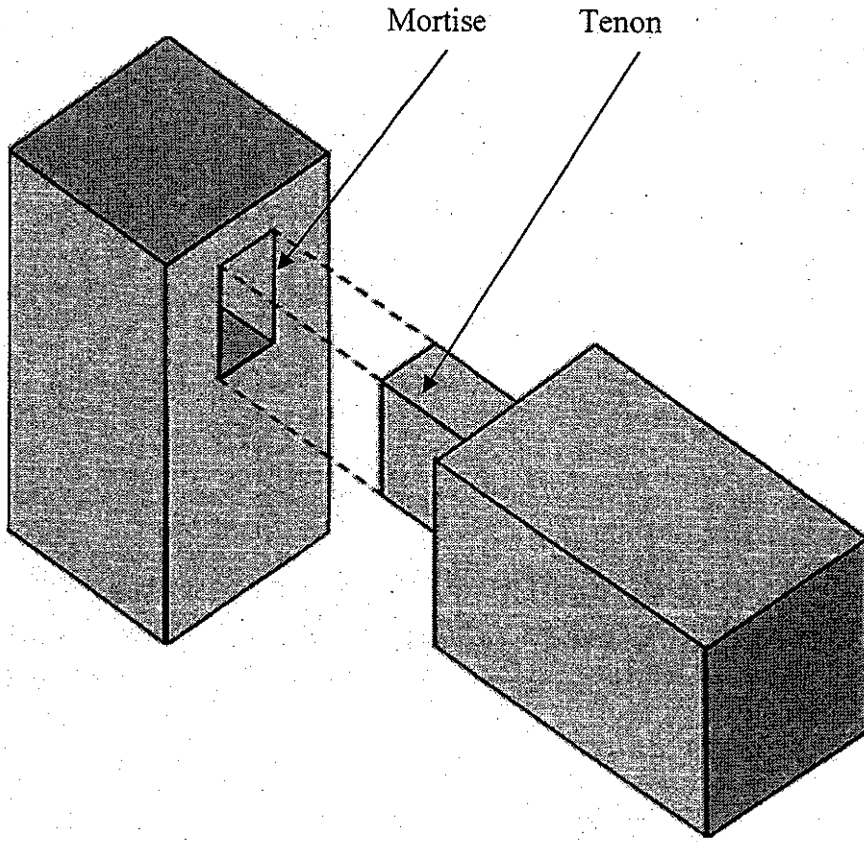
SMACNA. 1994. HVAC Systems Commissioning Manual. 1st ed. Sheet Metal and Air Conditioning Contractors' National Association, Inc., Chantilly, VA.

Trewartha, G.T. 1943. *An Introduction to Weather and Climate*. McGraw-Hill Book Company, New York, NY.

Thornburg, D. 2000. Filter Selection: a Standard Solution. *Engineering Systems* 17:6 pp. 74-80.

US EPA. 2001. Mold Remediation in Schools and Commercial Buildings. US Environmental Protection Agency, Office of Air and Radiation, Indoor Environments Division, Washington, D.C. EPA 402-K-01-001. March 2001. http://www.epa.gov/iaq/molds/mold_remediation.html

Figure 1



Mortise and Tenon Joint
http://en.wikipedia.org/wiki/Mortise_and_tenon

Figure 2

Unit Ventilator (Univent)

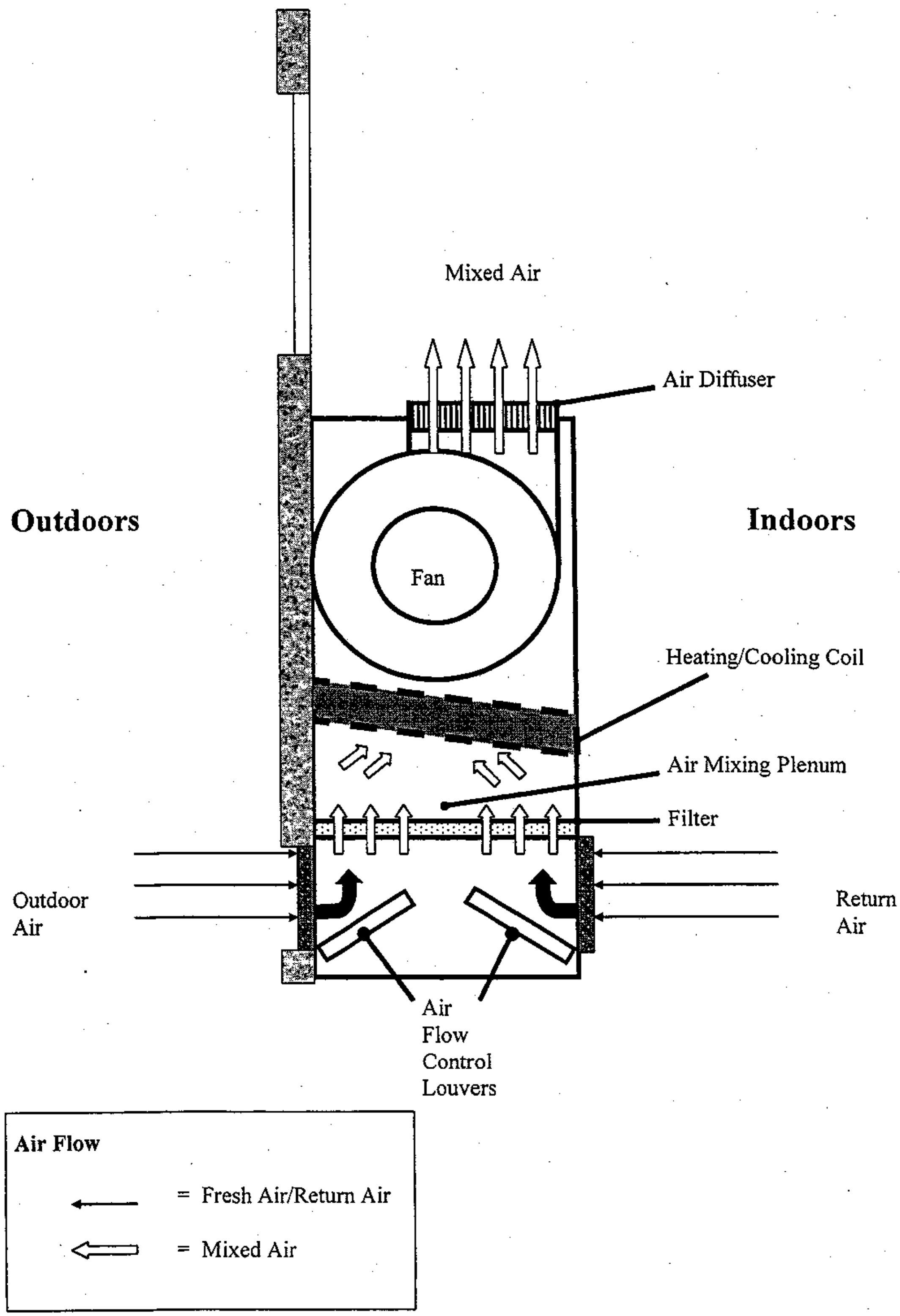


Figure 3

Cross Ventilation in a Building Using Open Windows and Transoms

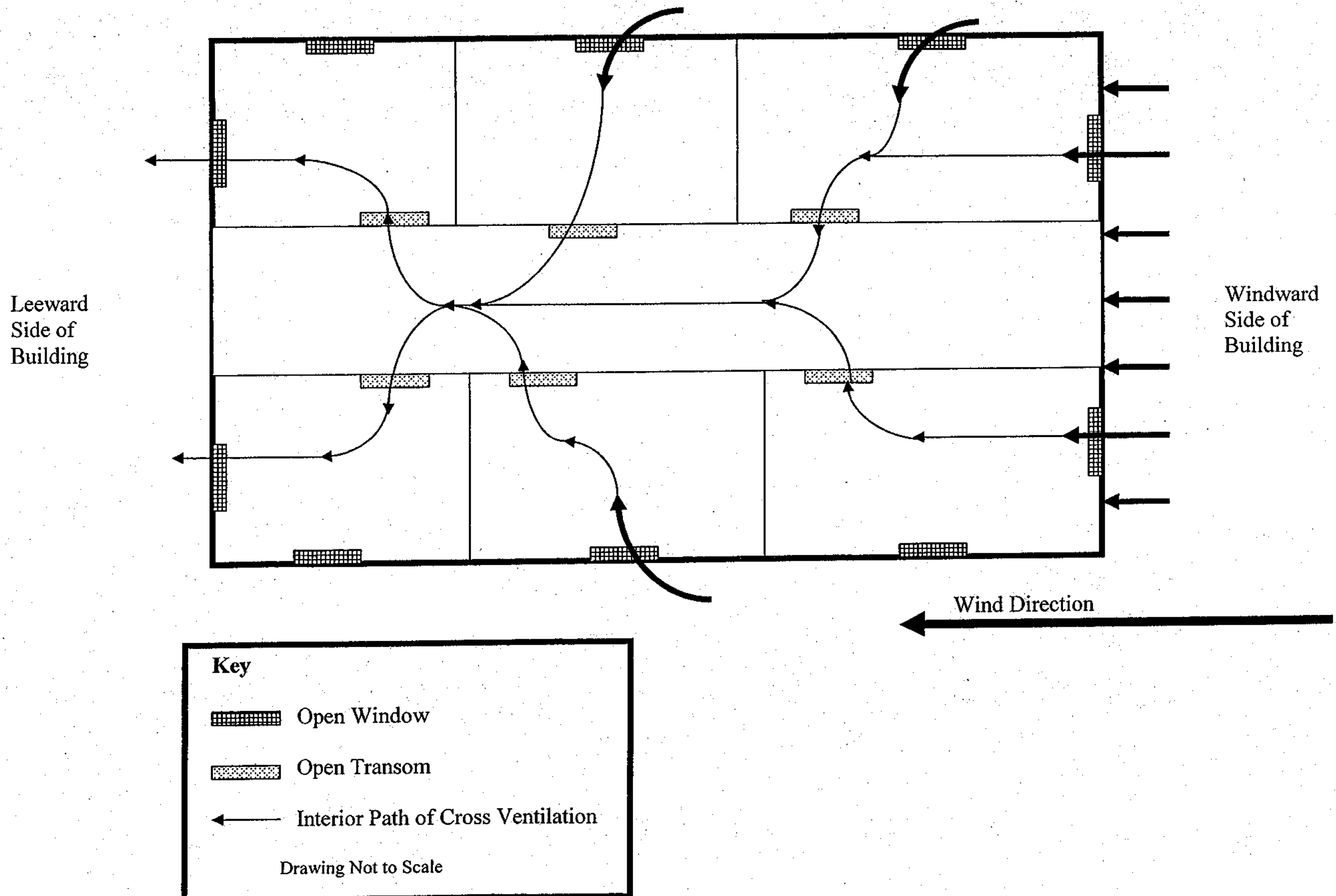
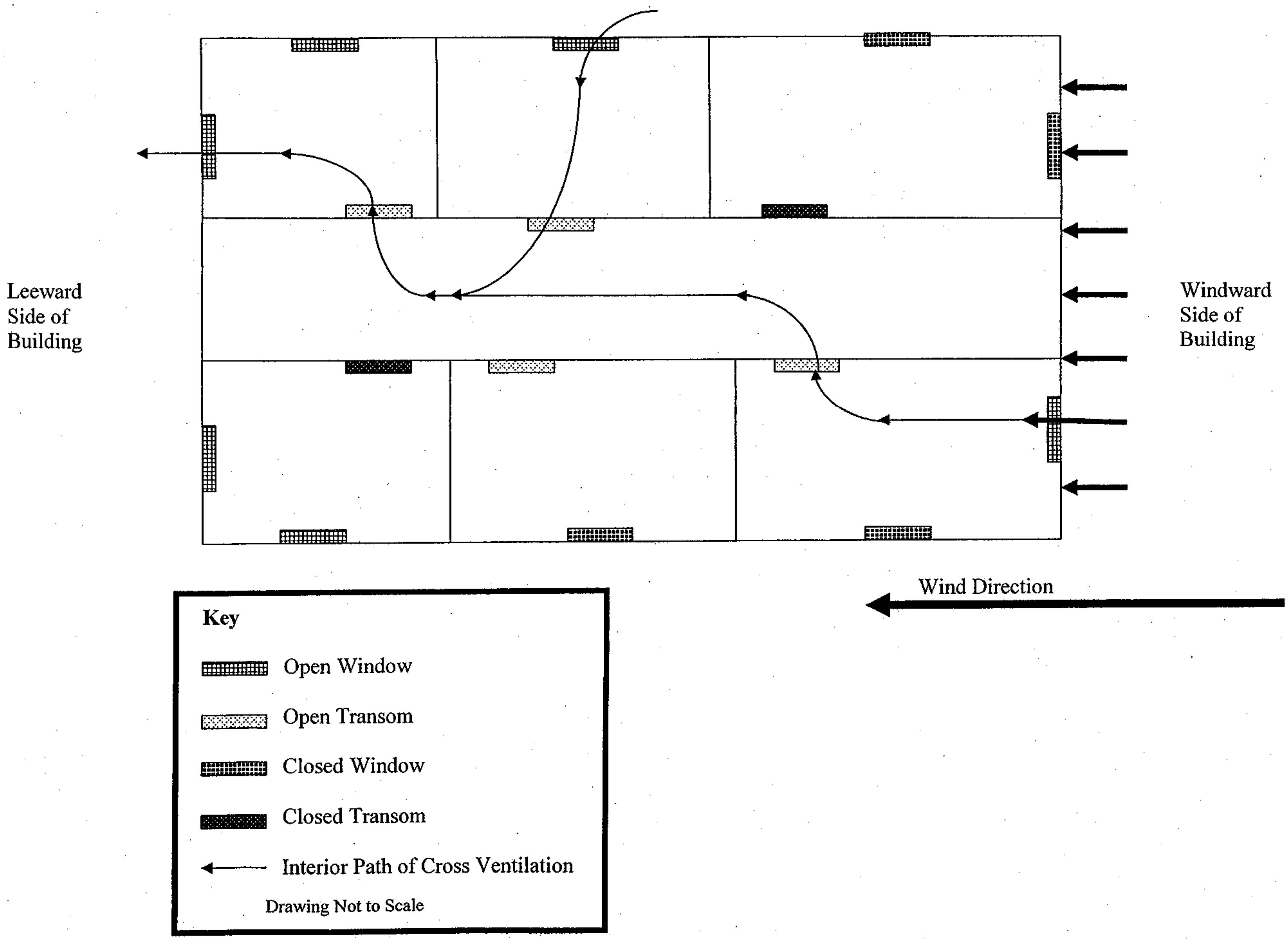
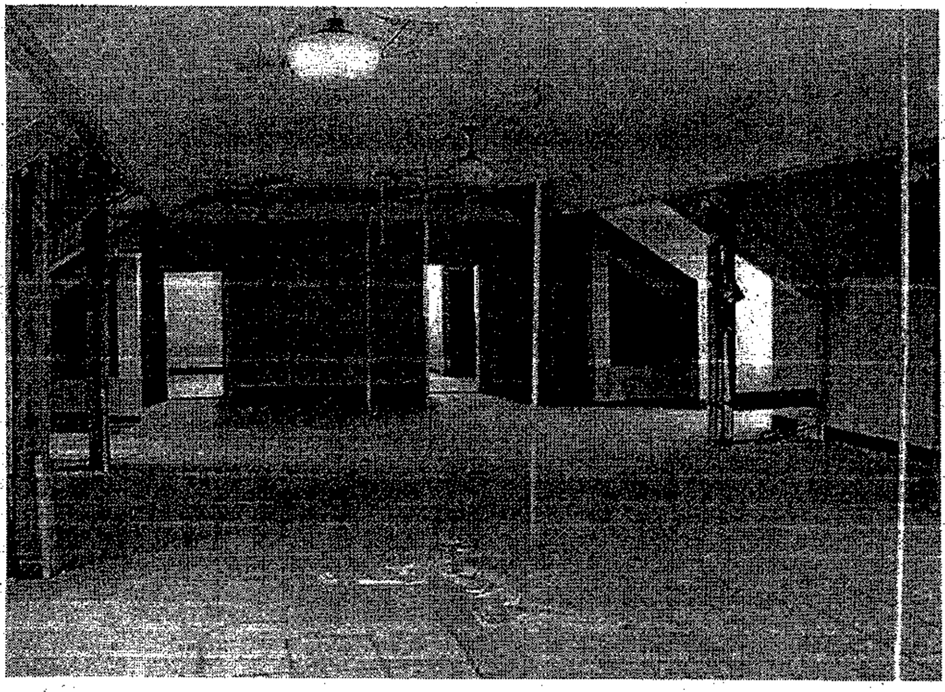


Figure 4 **Inhibition of Cross Ventilation in a Building with Several Windows and Transoms Closed**



Picture 1

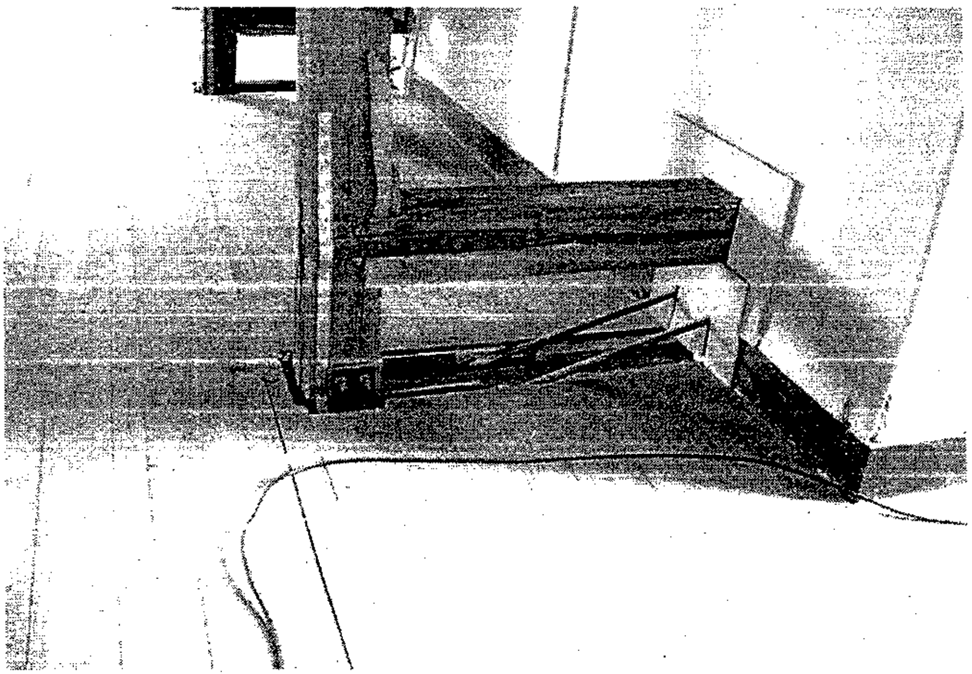


Tie Rods Connecting Auditorium Ceiling to the Roof

Picture 1A

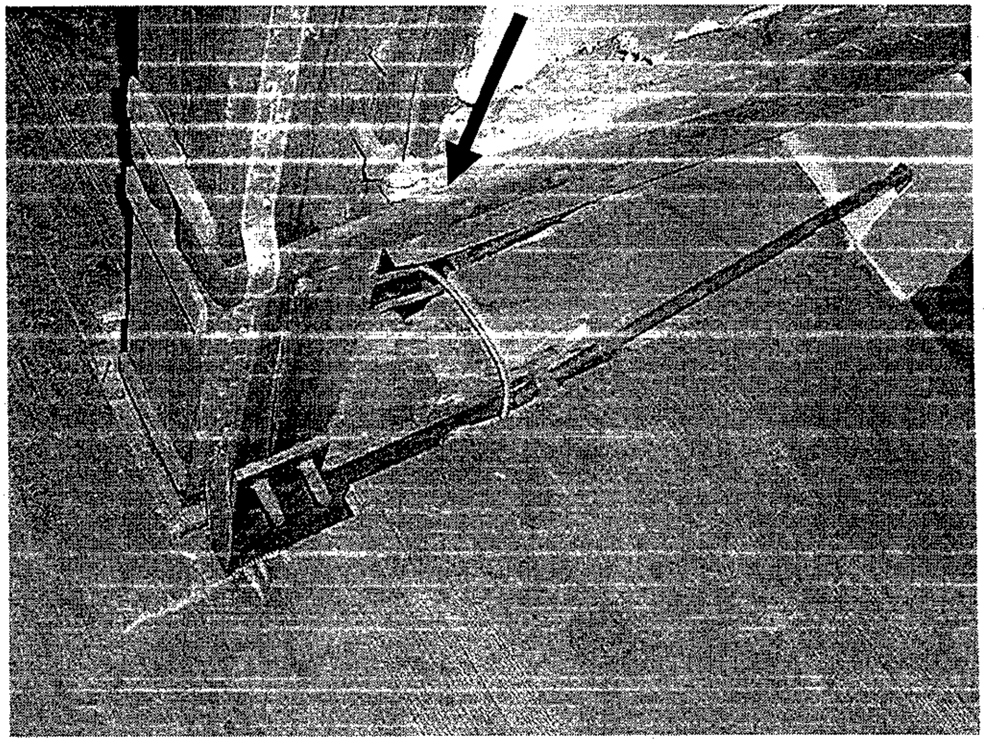
Close-Up of Tie Rod in Picture 1

Picture 2



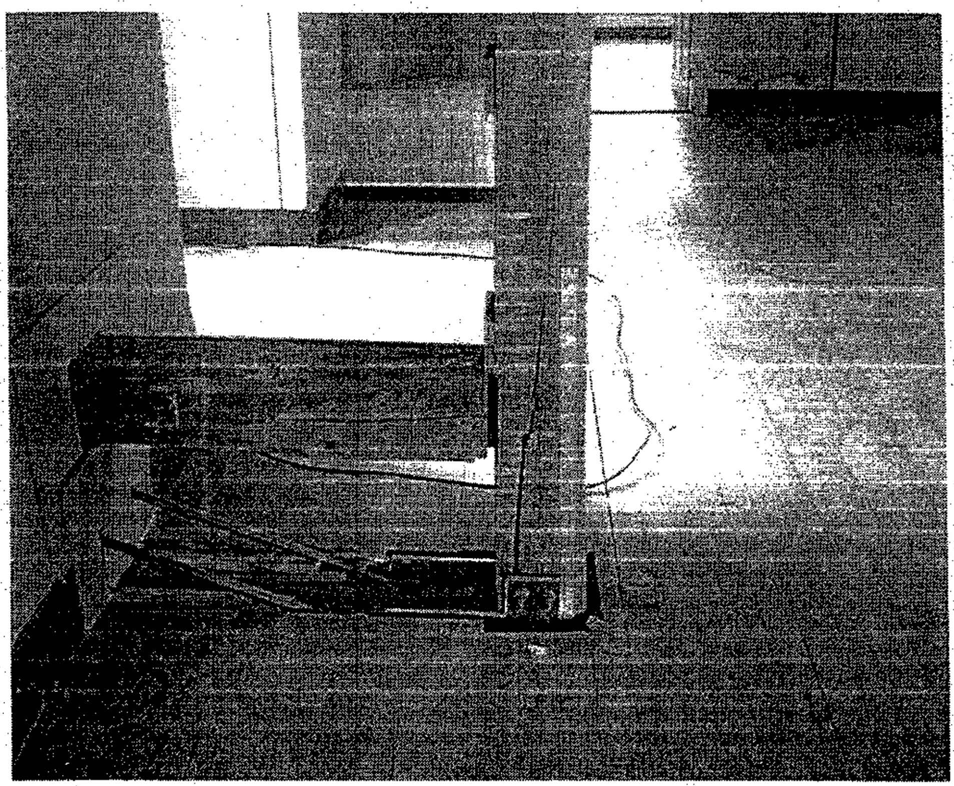
Wooden Horizontal Beam Inserted In Slot of Wooden Vertical Beam (Note Crack in Vertical Beam)

Picture 3



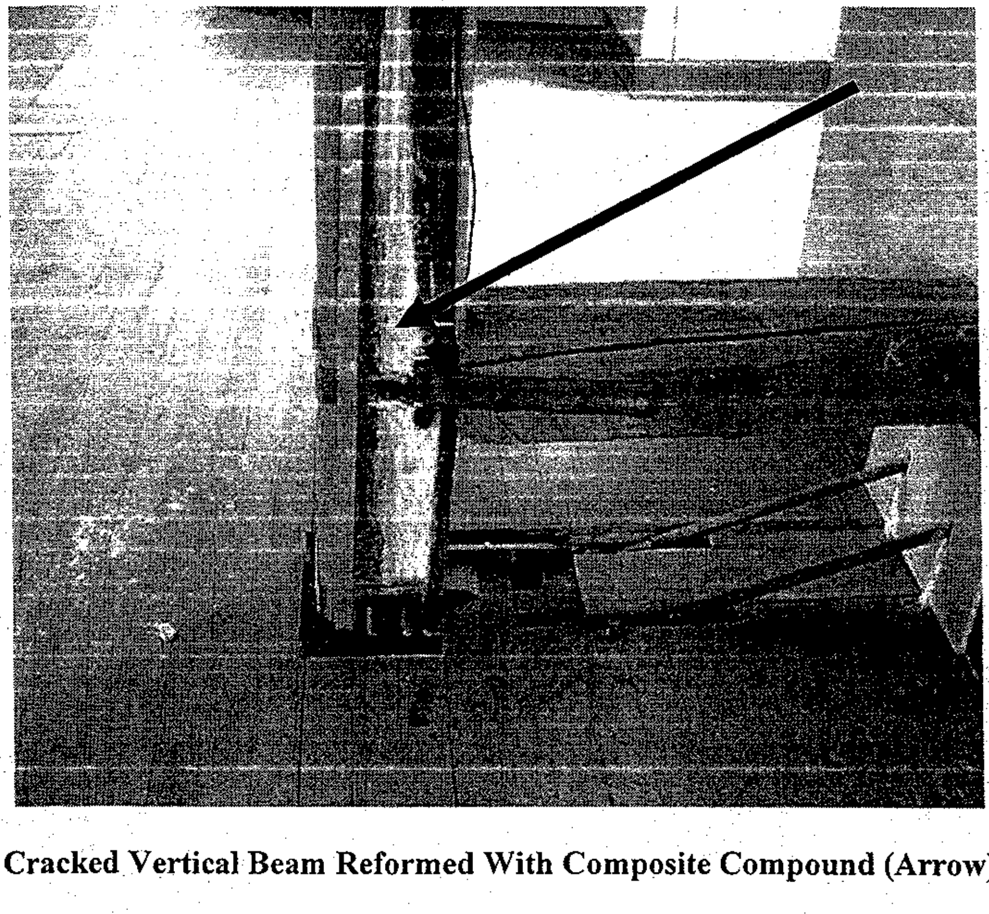
Original Metal Strap Spiked Into Place That Holds Horizontal and Vertical Horizontal Beams Together

Picture 4



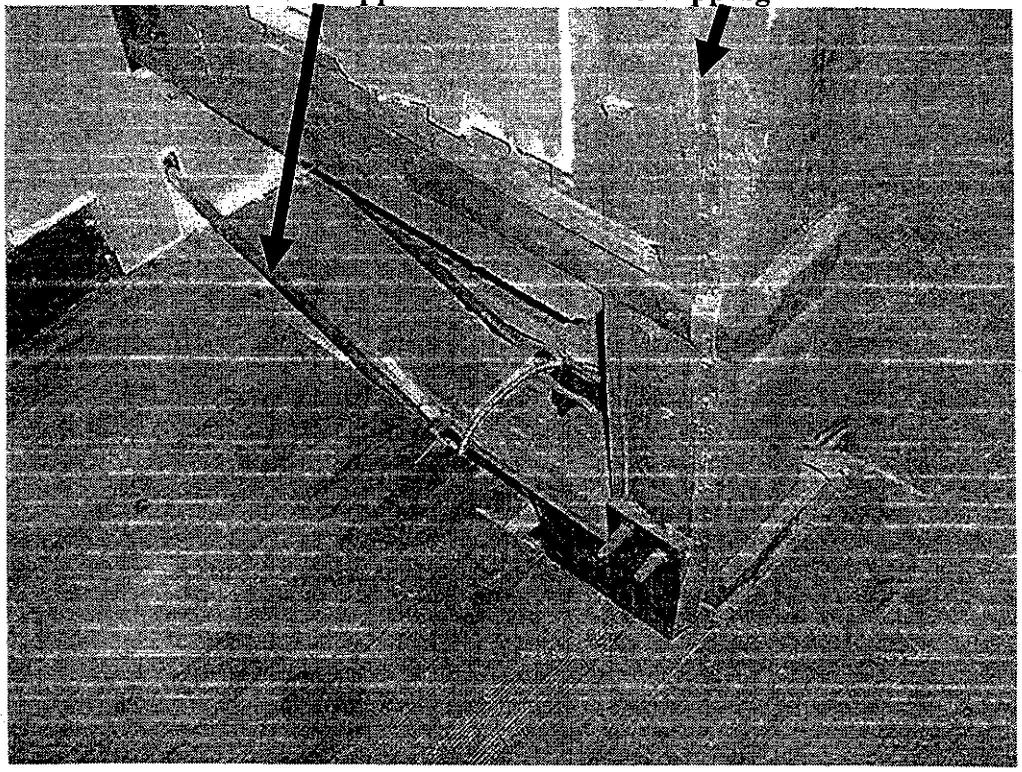
Cracked Vertical and Horizontal Beam

Picture 5



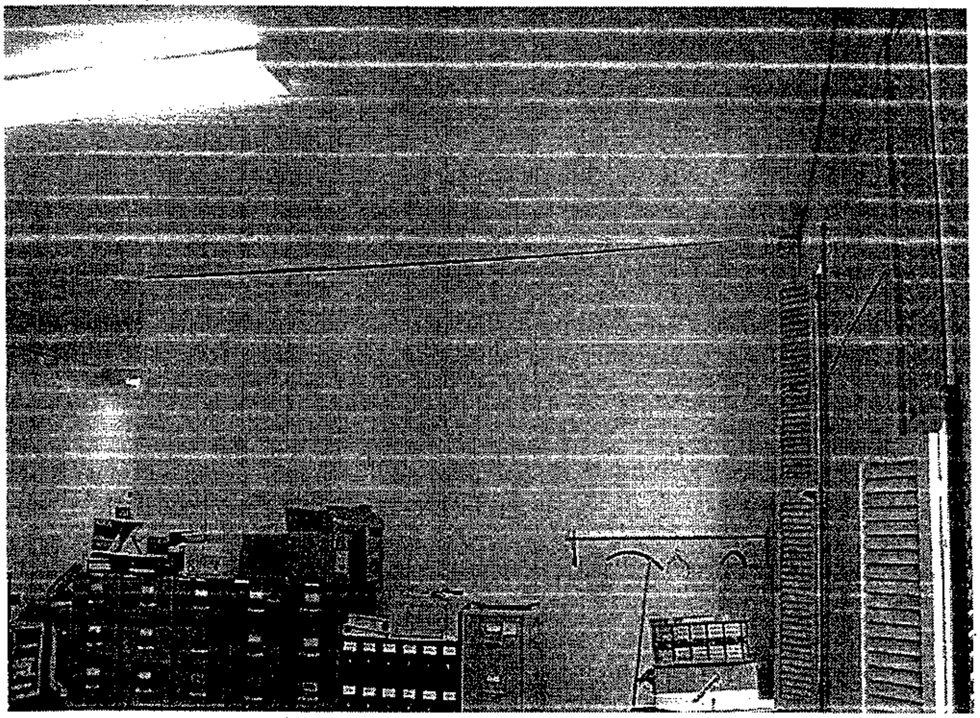
Cracked Vertical Beam Reformed With Composite Compound (Arrow)

Picture 6



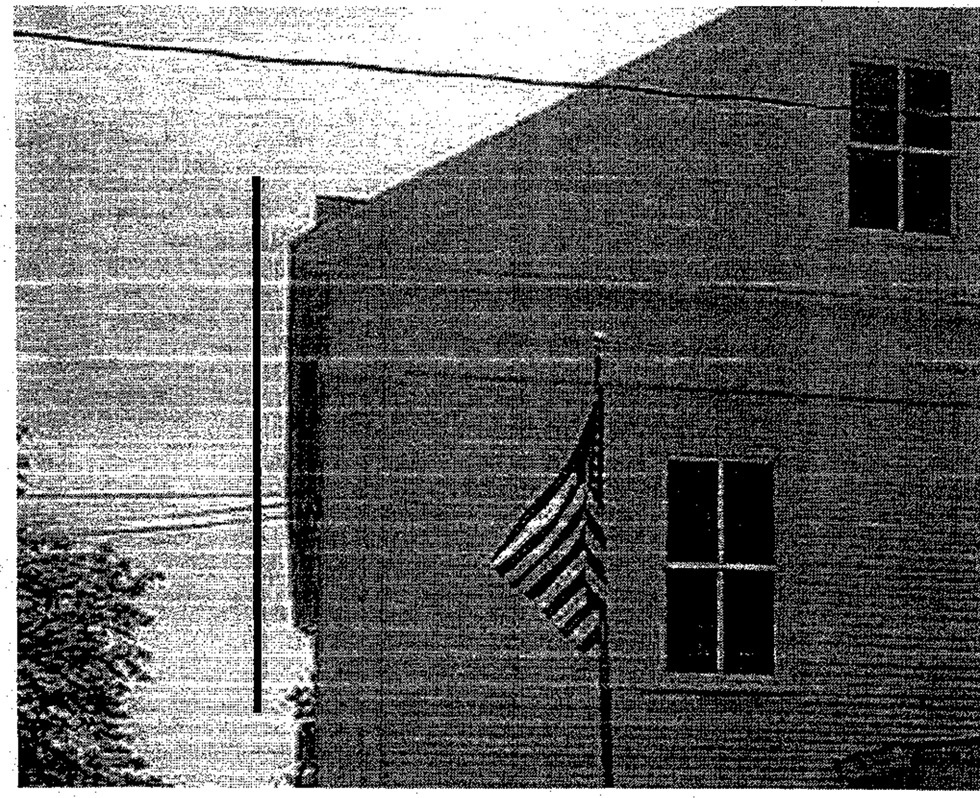
Supplemental Steel Supports and Strapping (Arrows) Installed To Reinforce Horizontal and Vertical Beams

Picture 7



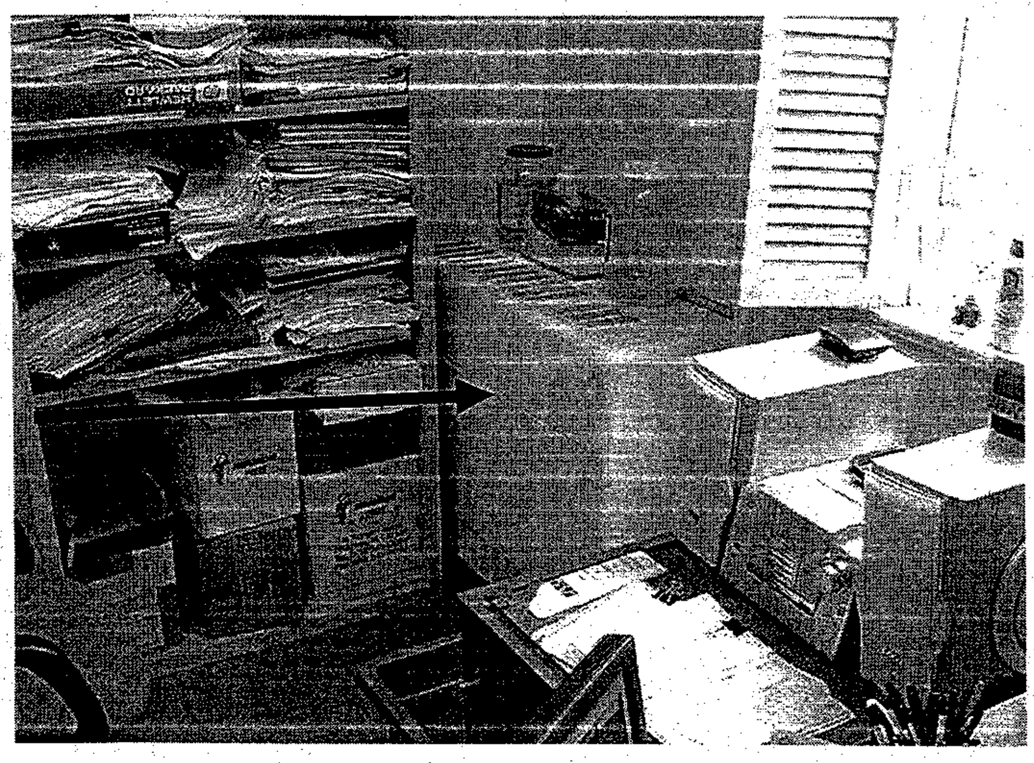
Gap Created By Repair Lifting Ceiling

Picture 8



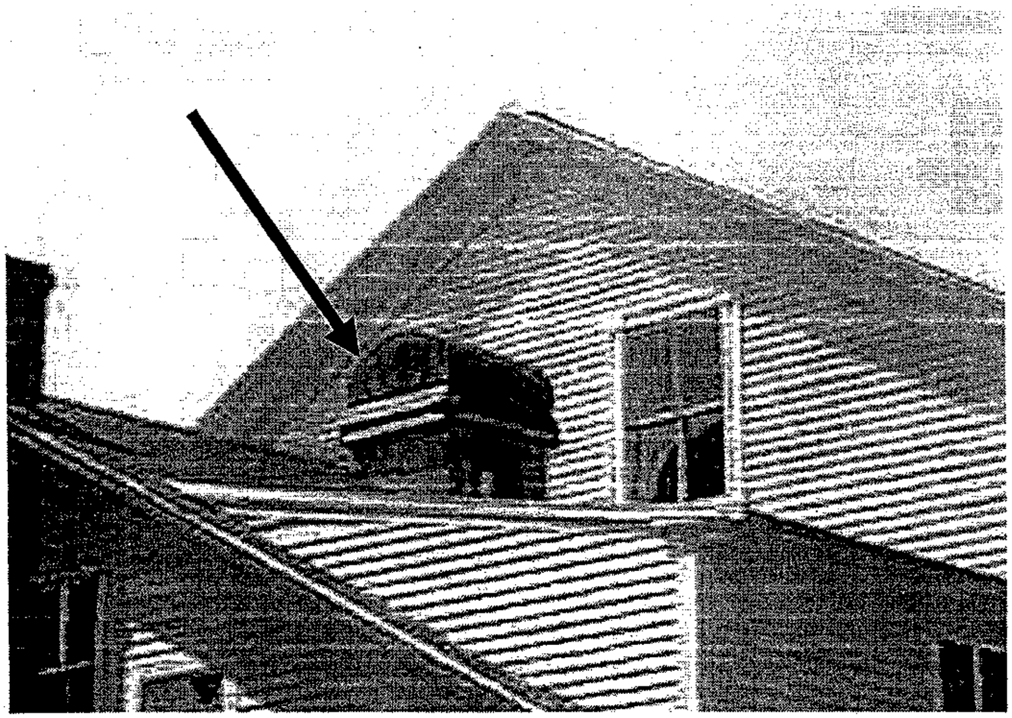
Bulging Second Floor Exterior Wall/Roof Edge, North Side (Line Added As Visual Aid)

Picture 9



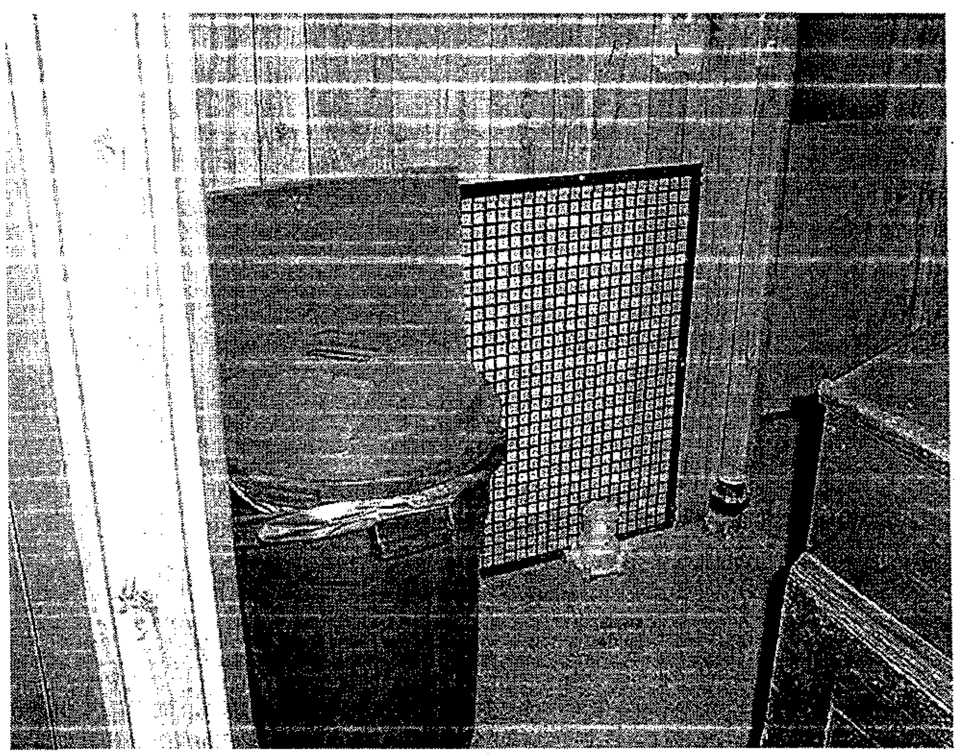
Univent with Wall Installed Over Casing

Picture 10



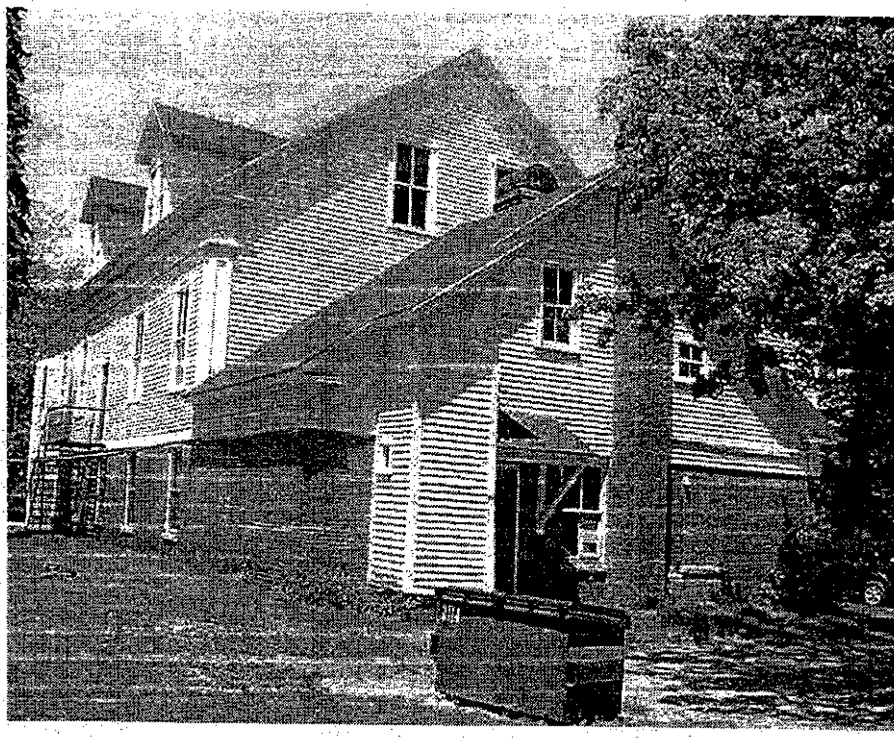
Exhaust Vent Housing on Roof

Picture 11



Exhaust Vent, First Floor, Note Plywood Blocking Vent

Picture 12

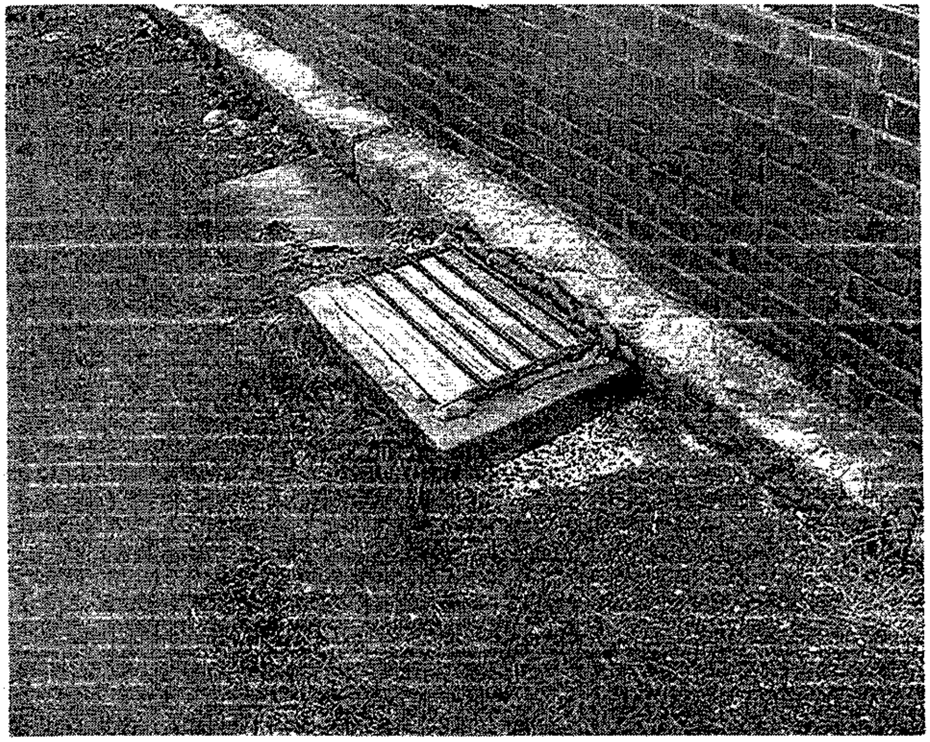


No Gutter/Downspout on Roof Edge, South Wall

Picture 13

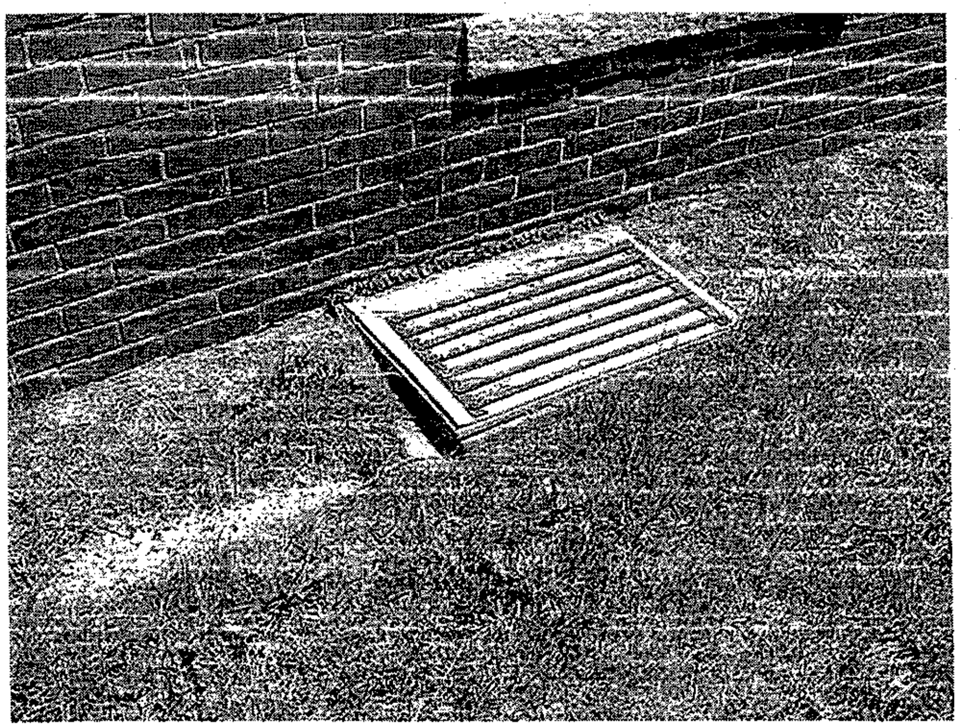
No Gutter/Downspout on Roof Edge, North Wall

Picture 14



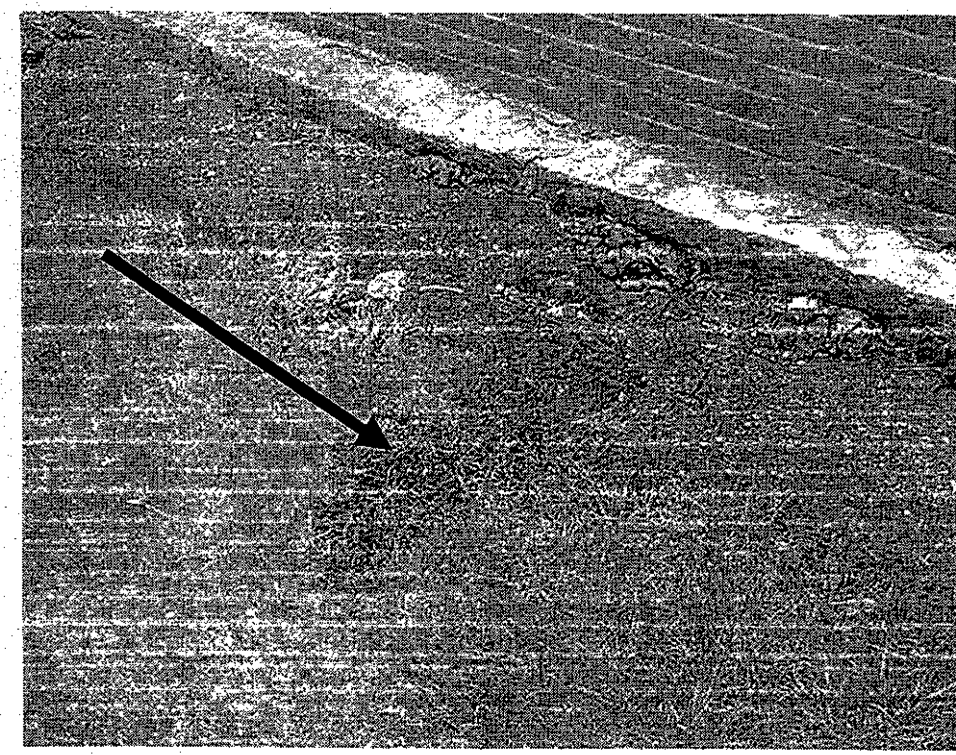
Crawlspace Vent Pit at Base of the Building, Note Plywood and Sealant

Picture 15



Crawlspace Vent Sealed with Plywood and Sealant Adjacent to Building Commissioner's Office, Note Tarmac Apron Overgrown with Grass

Picture 16



Damage Tarmac Apron, North Exterior Wall, Note Moss in Grass (Arrow) Indicating Heavy Water Exposure in This Area

Picture 17

Damage Tarmac Apron, North Exterior Wall

Picture 18

Walk-Off Carpet On Top Of Wall-To-Wall Carpet, Front Lobby

TABLE 1
Indoor Air Test Results
Westminster Town Hall, Westminster, MA
June 3, 2005

Location	Carbon Dioxide (*ppm)	Temp. (°F)	Relative Humidity (%)	Occupants in Room	Windows Openable	Ventilation		Remarks
						Supply	Exhaust	
Outside (Background)	346	77	37					
Board of health	918	71	51	1	Y	N	N	Door open
Building commissioners inner office	1219	71	54	1	Y	N	N	Door open
Building commissioner outer office	1285	71	54	1	Y	N	N	Reported water damage carpet, removed at time of assessment, no odor detected Door open
Town clerk	494	72	46	2	Y	N	N	Window open Door open
Town selectmen	485	72	44	0	Y	N	N	
Town selectmen administrator	395	71	45	1	Y	N	N	
Planning office	519	72	46	1	Y	Y[a]	N	Door open Univent off

*** ppm = parts per million parts of air**
[a] office share univent

Comfort Guidelines

Carbon Dioxide -	< 600 ppm = preferred 600 - 800 ppm = acceptable > 800 ppm = indicative of ventilation problems
Temperature -	70 - 78 °F
Relative Humidity -	40 - 60%

TABLE 1
Indoor Air Test Results
Westminster Town Hall, Westminster, MA
June 3, 2005

Location	Carbon Dioxide (*ppm)	Temp. (°F)	Relative Humidity (%)	Occupants in Room	Windows Openable	Ventilation		Remarks
						Supply	Exhaust	
Treasurer	793	74	48	2	Y	Y[a]	N	Door open Univent off
Workroom	728	74	48	0	Y	N	N	Mainframe room
Restrooms	751	73	48	0	Y	N	Y	Exhaust vent activated with light switch
Assessor's office, inner room	574	73	45	1	Y	Y	N	Door open Univent off
Assessor's office, outer room	649	73	46	1	Y	N	N	Door open
Town accountant	588	73	45	0	Y	Y	N	Door open Univent off
Auditorium	548	72	45	0	Y	Y	Y	Univents off Exhaust vent off

*** ppm = parts per million parts of air**
[a] office share univent

Comfort Guidelines

Carbon Dioxide -	< 600 ppm = preferred 600 - 800 ppm = acceptable > 800 ppm = indicative of ventilation problems
Temperature -	70 - 78 °F
Relative Humidity -	40 - 60%

Table 1-2

Appendix A

Carbon Dioxide and its Use in Evaluating Adequacy of Ventilation in Buildings

The Center of Environmental Health's (CEH) Emergency Response/Indoor Air Quality (ER/IAQ) Program examines indoor air quality conditions that may have an effect on building occupants. The status of the ventilation system, potential moisture problems/microbial growth and identification of respiratory irritants are examined in detail, which are described in the attached report. In order to examine the function of the ventilation system, measurements for carbon dioxide, temperature and relative humidity are taken. Carbon dioxide measurements are commonly used to assess the adequacy of ventilation within an indoor environment.

Carbon dioxide is an odorless, colorless gas. It is found naturally in the environment and is produced in the respiration process of living beings. Another source of carbon dioxide is the burning of fossil fuels. Carbon dioxide concentration in the atmosphere is approximately 250-600 ppm (NIOSH, 1987; Beard, 1982).

Carbon dioxide measurements within an occupied building are a standard method used to gauge the adequacy of ventilation systems. Carbon dioxide is used in this process for a number of reasons. Any occupied building will have normally occurring environmental pollutants in its interior. Human beings produce waste heat, moisture and carbon dioxide as by-products of the respiration process. Equipment, plants, cleaning products or school supplies normally found in any school can produce gases, vapors, fumes or dusts when in use. If a building has an adequately operating mechanical ventilation system, these normally occurring environmental pollutants will be diluted and removed from the interior of the building. The introduction of fresh air both increases the comfort of the occupants and serves to dilute normally occurring environmental pollutants.

An operating exhaust ventilation system physically removes air from a room and thereby removes environmental pollutants. The operation of univents in conjunction with the exhaust ventilation system creates airflow through a room, which increases the comfort of the occupants. If all or part of the ventilation system becomes non-functional, a build up of normally occurring environmental pollutants may occur, resulting in an increase in the discomfort of occupants.

The MDPH approach to resolving indoor air quality problems in schools and public buildings is generally two-fold: 1) improving ventilation to dilute and remove environmental pollutants and 2) reducing or eliminating exposure opportunities from materials that may be adversely affecting indoor air quality. In the case of an odor complaint of unknown origin, it is common for CEH staff to receive several descriptions from building occupants. A description of odor is subjective, based on the individual's life experiences and perception. Rather than test for a potential series of thousands of chemicals to identify the unknown material, carbon dioxide is used to judge the adequacy of airflow as it both dilutes and removes indoor air environmental pollutants.

As previously mentioned, carbon dioxide is used as a diagnostic tool to evaluate air exchange by building ventilation systems. The presence of increased levels of carbon dioxide in indoor air of buildings is attributed to occupancy. As individuals breathe, carbon dioxide is exhaled. The greater the number of occupants, the greater the amount of carbon dioxide produced. Carbon dioxide concentration build up in indoor environments is attributed to inefficient or non-functioning ventilation systems. The Occupational Safety and Health Administration (OSHA) standard for carbon dioxide is 5,000 parts per million parts of air (ppm). Workers may be exposed to this level for 40 hours/week, based on a time-weighted average (OSHA, 1997).

Carbon dioxide can be a hazard within enclosed areas with **no air supply**. These types of enclosed areas are known as confined spaces. Manholes, mines and sewer systems are examples of confined spaces. An ordinary building is not considered a confined space. Carbon dioxide air exposure limits for employees and the general public have been established by a number of governmental health and industrial safety groups. Each of these standards of air concentrations is expressed in parts per million (ppm). *Table 1* is a listing of carbon dioxide air concentrations and related health effects and standards.

The Department of Public Health uses a guideline of 800 ppm for publicly occupied buildings (SMACNA, 1998; Redlich, 1997; Rosenstock, 1996; OSHA, 1994; Gold, 1992; Burge et.al., 1990; Norback, 1990). A guideline of 600 ppm or less is preferred in schools due to the fact that the majority of occupants are young and considered to be a more sensitive population in the evaluation of environmental health status. Several sources indicate that indoor air problems *are significantly reduced* at 600 ppm or less of carbon dioxide (ACGIH, 1998; Bright et al., 1992; Hill, 1992; NIOSH, 1987). Inadequate ventilation and/or elevated temperatures are major causes of complaints such as respiratory, eye, nose and throat irritation, lethargy and headaches.

Appendix A

Air levels for carbon dioxide that indicate that indoor air quality may be a problem have been established by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). Above 1,000 ppm of carbon dioxide, ASHRAE recommends adjustment of the building's ventilation system (ASHRAE, 1989).

Carbon dioxide itself has no acute (short-term) health effects associated with low level exposure (below 5,000 ppm). The main effect of carbon dioxide involves its ability to displace oxygen for the air in a confined space. As oxygen is inhaled, carbon dioxide levels build up in the confined space, with a decrease in oxygen content in the available air. This displacement of oxygen makes carbon dioxide a simple asphyxiant. At carbon dioxide levels of 30,000 ppm, severe headaches, diffuse sweating, and labored breathing have been reported. No **chronic** health effects are reported at air levels below 5,000 ppm.

Air testing is one method used to determine whether carbon dioxide levels exceed the comfort levels recommended. If carbon dioxide levels are over 800-1,000 ppm, the MDPH recommends adjustment of the building's ventilation system. The Department recommends that corrective measures be taken at levels above 800 ppm of carbon dioxide in office buildings or schools. (Please note that carbon dioxide levels measured below 800 ppm may not decrease indoor air quality complaints). Sources of environmental pollutants indoors can often induce symptoms in exposed individuals regardless of the adequacy of the ventilation system. As an example, an idling bus outside a building may have minimal effect on carbon dioxide levels, but can be a source of carbon monoxide, particulates and odors via the ventilation system.

Appendix A

Therefore, the MDPH strategy of adequate ventilation coupled with pollutant source reduction/removal serves to improve indoor air quality in a building. Please note that each table included in the IAQ assessment lists CEH comfort levels for carbon dioxide levels at the bottom (i.e. carbon dioxide levels between 600 ppm to 800 ppm are acceptable and <600 ppm is preferable). While carbon dioxide levels are important, focusing on these air measurements in isolation to all other recommendations is a misinterpretation of the recommendations made in these assessments.

Appendix A

Table 1
Carbon Dioxide Air Level Standards

Carbon Dioxide Level	Health Effects	Standards or Use of Concentration	Reference
250-600 ppm	None	Concentrations in ambiant air	Beard, R.R., 1982 NIOSH, 1987
600 ppm	None	Most indoor air complaints eliminated, used as reference for air exchange for protection of children	ACGIH, 1998; Bright et al., 1992; Hill, 1992; NIOSH 1987
800 ppm	None	Used as an indicator of ventilation inadequacy in schools and public buildings, used as reference for air exchange for protection of children	Bell, A. A., 2000; SMACNA, 1998; Redlich, 1997; Rosenstock, 1996; OSHA, 1994; Gold, 1992; Burge et al., 1990; Norback, 1990
1000 ppm	None	Used as an indicator of ventilation inadequacy concerning removal of odors from the interior of building.	ASHRAE, 1989
950-1300 ppm*	None	Used as an indicator of ventilation inadequacy concerning removal of odors from the interior of building.	ASHRAE, 1999
5000 ppm	No acute (short term) or chronic (long-term) health effects	Permissible Exposure Limit/Threshold Limit Value	ACGIH, 1999 OSHA, 1997
30,000 ppm	Severe headaches, diffuse sweating, and labored breathing	Short-term Exposure Limit	ACGIH, 1999 ACGIH. 1986

* outdoor carbon dioxide measurement +700 ppm

Appendix A

References

ACGIH. 1999. Guide to Occupational Exposures-1999. American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

ACGIH. 1998. Industrial Ventilation A Manual of Recommended Practice. 23rd Edition. American Conference of Governmental Industrial Hygienists. Cincinnati, OH.

ACGIH. 1986. Documentation of the Threshold Limit Values. American Conference of Governmental Industrial Hygienists. Cincinnati, OH.

ASHRAE. 1989. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigeration and Air Conditioning Engineers. ANSI/ASHRAE 62-1989.

ASHRAE. 1999. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigeration and Air Conditioning Engineers. ANSI/ASHRAE 62-1999.

Beard, R.R. 1982. Chapter Fifty-two, Inorganic Compounds of Oxygen, Nitrogen, and Carbon. *Patty's Industrial Hygiene and Toxicology, Vol. IIc. 3rd ed.* Clayton, G. D. & Clayton, F. E., eds. John Wiley & Sons, New York, NY.

Bright, P.; Mader, M.; Carpenter, D.; and Hermon-Cruz, I.Z. 1992. Guideline for Indoor Air Surveys. Brooks Air Force Base, TX. Armstrong Laboratory, Occupational and Environmental Health Directorate. NTIS AL-TR-1992-0016.

Burge, H. and Hoyer, M. 1990. Focus On ... Indoor Air Quality. Appl. Occup. Environ. Hyg. 5(2):88.

Gold, D. 1992. Indoor Air Pollution. Clinics in Chest Medicine. 13(2):224-225.

Hill, B.; Craft, B.; and Burkart, J. 1992. Carbon Dioxide, Particulates and Subjective Human Responses in Office Buildings without Histories of Indoor Air Quality Problems. Appl. Occup. Environ. Hyg. 7(2): 101-111.

NIOSH. 1987. Guidance for Indoor Air Quality Investigations. Cincinnati, OH. National Institute for Occupational Safety and Health, Hazards Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluation and Field Studies.

Norback, D.; Torgen, M.; and Edling, C. 1990. Volatile Organic Compounds, Respirable Dust, and Personal Factors Related to Prevalence and Incidence of Sick Building Syndrome in Primary Schools. British Journal of Industrial Medicine. 47:740.

OSHA. 1994. Occupational Safety and Health Administration. Indoor Air Quality (Proposed Regulation), Federal Register 59:15968-16039, (1994) Appendix A.

Appendix A

OSHA. 1997. Limits for Air Contaminants. Occupational Safety and Health Administration. Code of Federal Regulations. 29 C.F.R 1910.1000 Table Z-1-A.

Redlich, C.; Sparer, J.; and Cullen, M. 1997. Sick-building Syndrome. Lancet. 349:1016.

Rosenstock, L. 1996. NIOSH Testimony to the U.S. Department of Labor on Air Quality, Appl. Occup. Environ. Hyg. 11(12):1368.

SMACNA. 1998. Indoor Air Quality: A Systems Approach. 3rd ed. Sheet Metal and Air Conditioning Contractors' National Association, Inc, Chantilly, VA.
National Association, Inc.